Transdisciplinary Training
Key Components and Prerequisites for Success

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Abstract: The training of transdisciplinary science is distinct in its intention to develop scientists who synthesize the theoretical and methodologic approaches of different disciplines. As a result, transdisciplinary scientists are better prepared to address the complexities of health problems. The most common form of transdisciplinary training is the multi-mentor apprenticeship model, with each mentor training from his or her own discipline. The transdisciplinary trainee is faced with many challenges, including learning the languages and cultures of different disciplines along with learning how to navigate within and between disciplines. The trainee also confronts unique career development risks. The climb up the academic ladder can be slower, rougher, and less linear than that of the trainee's single-disciplinary-trained peers. A number of factors can help the trainee in overcoming the challenges: being able to develop a core set of values and behaviors that are essential for transdisciplinary scientists; having the commitment and support of training institutions, training directors, and mentors; and having training structures and processes in place to prevent the training and trainee from naturally regressing back to familiar single-disciplinary approaches. There is relatively little known empirically about transdisciplinary training. Future efforts can focus on developing a better understanding of the unique characteristics of transdisciplinary training, identifying the effective elements that relate to training outcomes, defining the critical outcome metrics at different time points during and following training, and creating toolkits to help with training processes.
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Introduction

The complexity of health problems, combined with rapid technologic advances to address them, has intensified the call for researchers to more explicitly break from isolated disciplines and use integrative, transdisciplinary, scientific approaches.[1] Transdisciplinary science can be conducted by collaborative teams with members from different scientific disciplines and even nonscientific professions (e.g., architecture, city planning, law). Alternatively, transdisciplinary science can be conducted by individual scientists who become integrative in their disciplinary approach to research.[2,3] Kessel et al.[4] present case studies of collaborative teams of scientists and individual scientists who are integrative in their work. Examples of case studies from their volume will be used to illustrate key points. For example, Jay Kaplan, a physical anthropologist at Wake Forest University, and Stephen Manuck, a psychologist at the University of Pittsburgh, use a team approach. Each relies on his own discipline-specific expertise to collaborate in their examination of the role of behavior in the development of heart disease.[5] On the other hand, Richard J. Davidson is an individual scientist who is integrative in his examination of the neural substrates of emotion.[6]

Transdisciplinary training can occur at any level of career development. At an early career stage, doctoral training can be inherently transdisciplinary. The PhD program in Social Ecology at the University of California Irvine is an example of a doctoral program that has an established record of training scientists who are transdisciplinary. Early career transdisciplinary training is advantageous in that students are more readily acceptable of different disciplinary approaches and learn to conceptualize across theoretical perspectives and multiple levels at the outset of their scientific experience. Early career transdisciplinary training has the limitation, however, of not providing what some, including Kaplan,[5] would consider important. Students do not receive grounding in a set of specific disciplinary skills relating to a particular body of knowledge. At later career stages, scientists are better-grounded in a disciplinary approach. The Robert Wood Johnson Foundation Health and Society Scholars program trains postgraduate fellows who address the determinants of health problems across biological, behavioral, environmental, and social levels. Transdisciplinary training at

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later career stages is disadvantageous when scientists are more fixed in their scientific ways and less open to incorporating new disciplinary approaches into their work.

Early in training at the undergraduate or early graduate levels, a more didactic-intensive approach is used. At the advanced graduate level and beyond, an apprenticeship model is more typical, with mentoring playing a central role in transdisciplinary training. In the single-mentor apprenticeship approach, a transdisciplinary researcher serves as a mentor, and a model, for a student who learns to conduct transdisciplinary research. The single-mentor model in transdisciplinary training is not common.[7–9] The use of multiple mentors is often a necessity because most scientists who can serve as mentors were trained in a single discipline, operate from a single disciplinary framework, and are employed within traditionally structured departments. In this approach, each mentor on the team trains in his or her separate discipline. With a team of mentors, a trainee's proximity to mentors is desirable but not always certain. Mentors can be located within separate departments at the same institution or at separate institutions as part of geographically dispersed networks.[10,11] In this paper, the focus is on training at the advanced graduate and postdoctoral levels, using an apprenticeship model with multiple mentors, to develop scientists who will individually approach research from a transdisciplinary perspective.

Conceptual Understanding of Transdisciplinary Training

The distinction between transdisciplinary training and other integrative training approaches (e.g., interdisciplinary training) is not yet delineated. The distinction in training presented here follows the distinguishing of different integrative research approaches made by Rosenfield[12] and, more recently, Rosenfield and Kessel.[13] They distinguish different integrative research approaches on the explicitness in which the team members integrate disciplinary perspectives and analytic levels. Similarly, it is suggested here that in multidisciplinary training, trainees are taught a single disciplinary approach but also learn to work alongside researchers from other disciplines. The intention of interdisciplinary training, on the other hand, is to develop scientists who possess a working knowledge of different disciplinary conceptual frameworks and methodologic tools. Transdisciplinary training is defined by its intention to produce scientists who are able to synthesize theoretical and methodologic aspects of different disciplines in a defined problem area. The differences in training approaches lie in the presence and level of disciplinary integration involved, with single-disciplinary training and transdisciplinary training anchoring the two extremes.

Constraints and Challenges in Transdisciplinary Training

The challenges in transdisciplinary training extend beyond learning topic knowledge and research skills in different disciplines. The challenges occur at the intrapersonal, interpersonal, and systems levels. In encountering all the challenges, the transdisciplinary trainee confronts some forces that act to push him or her away from engaging in unfamiliar disciplines and other forces that act to pull him or her back into operating solely from the secure, familiar disciplinary fold. In Figure 1, the challenges in transdisciplinary training are presented along with facilitating factors that influence training outcomes.

A Tale of Two Learning Cultures

Obstacles develop when the natural learning style of the transdisciplinary trainee conflicts with the teaching approaches used in different disciplines and at different levels of analysis.[14,15] In their team approach to examining the determinants of cardiovascular health, Gary Berntson, a more basic psychobiological and behavioral neuroscientist, and John Cacioppo, a social psychologist, recognize the challenges in learning to integrate factors across a basic biological level and a social–cultural level.[16] For example, a trainee who is particularly strong in memorizing and reproducing large amounts of factual information may be facile in learning human biology, which is anchored in concrete anatomy and genetics. That trainee could become bewildered when shifting to social psychology, which is based on a complex set of abstractions that represent the interacting actions and influences of relationships among individuals, groups, societies, and cultures. Thus, it is important for transdisciplinary trainees to have a sense of how learning occurs in different disciplines in addition to knowing what needs to be learned. It is especially challenging for trainees to venture into the space that exists between the two disciplines, where the learning and teaching approaches have yet to be established.[17]

Learning Language Within the Learning Cultures

Each disciplinary culture has a language with specialized terminology that allows for efficient communication betweens its members. Success in transdisciplinary training hinges on the capacity of trainees to be able to speak the different disciplinary languages.[2,9,13,17,18] Learning different disciplinary languages is one of the most time-consuming, confusing, and frustrating experiences for trainees. Once successful, however,

the transdisciplinary trainee not only learns elements of each language, but is unique in speaking a hybrid language that develops from the core terminology of each disciplinary language. The development of this hybrid language is part of the innovation that occurs in transdisciplinary training and research, along with the development of unique theoretical perspectives and methodologic approaches.

Operating in the Ambiguity Among the Disciplines

Transdisciplinary trainees, who are already challenged with learning how to maneuver within separate disciplinary structures, also have to learn how to operate in the ambiguous space between the disciplines.[17] This space is where constructs are ill-defined, methods not yet established, and training objectives unspecified (e.g., topic knowledge, methods, and skills to be learned). This is uncharted territory with terrain that only the trainee traverses. Mentors, who remain comfortably situated within the confines of their respective disciplines, are limited in their ability to guide trainees through the ambiguity existing between disciplines. The trainee, by confronting the unique and complex theoretical and methodologic problems alone, ultimately creates innovative solutions that reflect a synthesis of disciplinary perspectives, a formation of innovative hypotheses, and a creation of new methodologic tools.

Engaging with Unfamiliar Others in an Unsupportive Environment

Effective interpersonal relationships are central to successful collaborative ventures. In transdisciplinary training, relationship-building involves extra challenges. Faculty and trainee relationships that occur across disciplinary lines require engaging with those who not only speak different disciplinary languages but also use
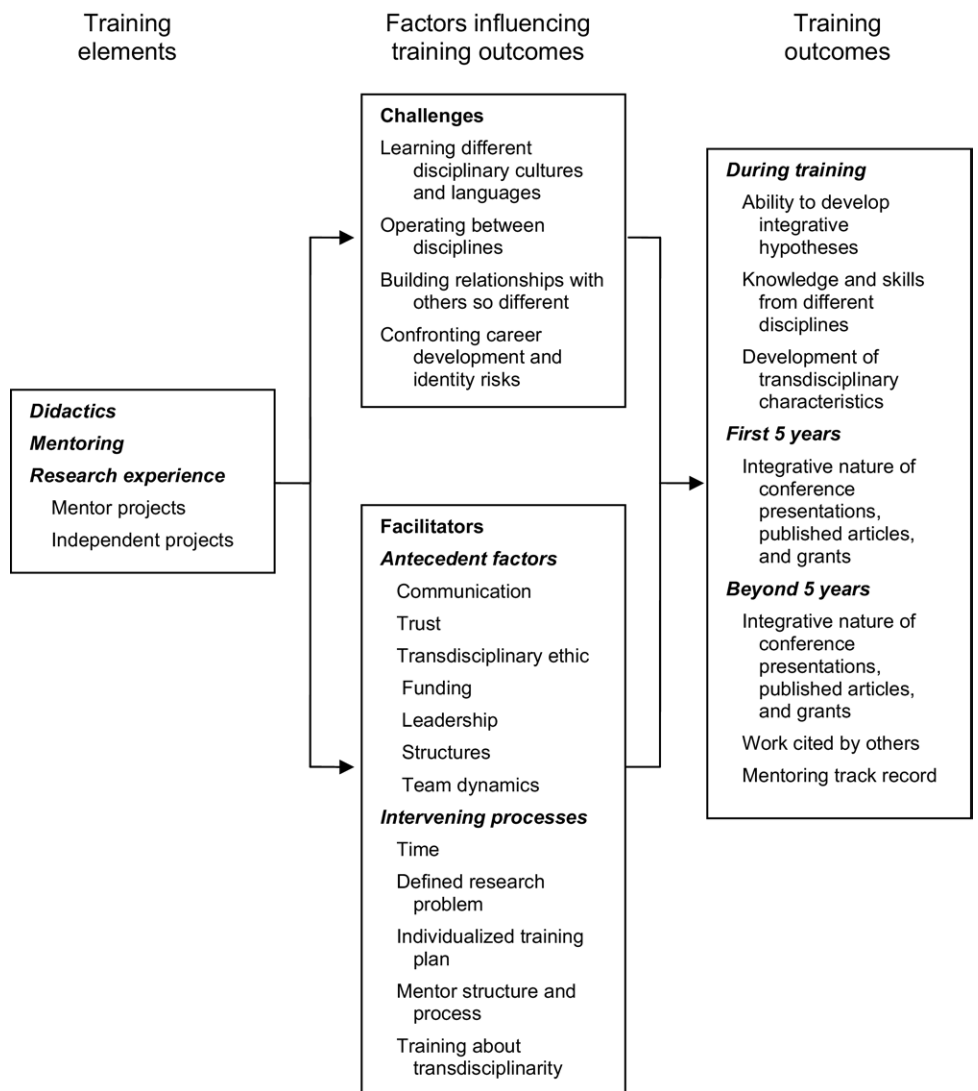
Training elements

> **Didactics**
> **Mentoring**
> **Research experience**
>   Mentor projects
>   Independent projects

Factors influencing training outcomes

> **Challenges**
> Learning different disciplinary cultures and languages
> Operating between disciplines
> Building relationships with others so different
> Confronting career development and identity risks

> **Facilitators**
> **Antecedent factors**
>   Communication
>   Trust
>   Transdisciplinary ethic
>   Funding
>   Leadership
>   Structures
>   Team dynamics
> **Intervening processes**
>   Time
>   Defined research problem
>   Individualized training plan
>   Mentor structure and process
>   Training about transdisciplinarity

Training outcomes

> **During training**
>   Ability to develop integrative hypotheses
>   Knowledge and skills from different disciplines
>   Development of transdisciplinary characteristics
> **First 5 years**
>   Integrative nature of conference presentations, published articles, and grants
> **Beyond 5 years**
>   Integrative nature of conference presentations, published articles, and grants
>   Work cited by others
>   Mentoring track record

Figure 1. Transdisciplinary training elements, facilitating and challenging factors, and outcomes

unfamiliar scientific approaches and who may harbor a subtle antagonism toward disciplinary approaches other than their own.

The antagonism can be a byproduct of the culture of traditional academic structures that breeds disciplinary stereotyping, prejudice, and rivalry. Traditional academics reinforce narrowly defined disciplines with well-defined boundaries.[1,19] The similarities among the disciplines are not adequately recognized and the differences between them are not well-respected.[20] The situation is further exacerbated by interdepartmental rivalry that occurs as departments compete for finite resources from the parent institution. In the traditional academic environment, faculty and trainees who need support in their efforts to cross disciplinary lines are instead discouraged. Davidson[6] considers the trainee's ability to cross disciplinary, departmental, and institutional divides a critical aspect of transdisciplinary train-

ing. As a graduate student in psychology at Harvard, he crossed disciplinary and departmental lines to learn behavioral neurology from scientists at Harvard Medical School and crossed disciplinary, departmental, and institutional lines to learn neuroanatomy from scientists at Massachusetts Institute of Technology.

Confronting Compromises in Career Development and Confusion in Identity

The climb onto and up the academic ladder can leave transdisciplinary researchers feeling misunderstood, undervalued, and without a clearly defined disciplinary identity.[8,9,15,18,21,22] The fundamental dilemma is the perception that the trainee is a jack-of-all-trades but master of none.

After investing extra time to complete formal training, the trainee may face compromised prospects in becoming employed. Individuals trained in transdisciplinary approaches are competitive for positions at the boundaries between disciplines (e.g., positions in comprehensive cancer centers) but are at a disadvantage in seeking specialist jobs within traditional academic departments.

Once hired, transdisciplinary researchers may find that their paths through the academic ranks may not be as swift or smooth as that of their more traditionally trained peers.[1] Transdisciplinary researchers wonder how they will fare in publishing manuscripts and obtaining grants when their theoretical and methodologic work does not reside neatly within any one discipline.[12,13] As transdisciplinary researchers, they face grant and manuscript reviewers who have a natural tendency to be critical of work that is unfamiliar. Davidson,[6] as an individual scientist, and Berntson and Cacioppo,[16] as collaborative scientists, encountered early career challenges in obtaining grant funding because the innovative, transdisciplinary nature of their research was not recognized by review panels representing more traditional disciplines and perspectives. Davidson's experience[6] was that grant reviewers at the time did not recognize that emotions could affect health and were not competent in both biological measures and emotion research.

Even when they secure grants and publish articles, transdisciplinary researchers face hurdles in having their original contributions recognized by members of promotion and tenure committees. Publications that are outside of recognized discipline-specific journals, or that are team-authored, are held in lower regard.[1,12,13] Light and her colleagues[23] at the University of North Carolina note that collaborative cross-disciplinary research frequently requires that five or more authors share credit on important papers. In some cases the co-authors will have contributed almost as much as the first author, yet they receive substantially less recognition.

Factors That Facilitate Overcoming the Challenges

Despite the challenges inherent in transdisciplinary training, formal investments and commitments continue to be made by funding agencies, institutions, professional societies, publishers, leaders, mentors, and trainees. Institutions recognize that transdisciplinary training initiatives can help fertilize interdisciplinary and interdepartmental research, opening opportunities for new funding sources. Identifying the factors that can facilitate the training of transdisciplinary scientists will help to overcome the number of challenges that are present. The factors that are assumed to facilitate transdisciplinary training are, for the most part, based on observational data that have a very small evidence base. In Figure 1, factors that facilitate transdisciplinary training are presented along with the challenges that occur as they influence training outcomes.

Transdisciplinary training often involves a team approach with trainees, mentors, training program leaders, and institutional leaders all central to the process. It is helpful to explicate the factors that facilitate teamwork and team effectiveness. In their contemporary organizational psychology perspective, Kozlowski and Ilgen[24] report that factors that relate to team effectiveness are (1) cognitive processes (e.g., team climate, team mental models, and transactive memory); (2) motivational processes (e.g., cohesion, collective efficacy, group potency); and (3) behavioral processes (e.g., team competencies, functions, and regulatory mechanisms).

Transdisciplinary training functions best when its members capitalize on their own knowledge and expertise, are cohesive and confident, have resources allocated appropriately, and coordinate their collective actions well.[24,25] Problems in training develop when the team members do not have a shared strategic training vision, get derailed from their central focus by conflict, do not learn from their mistakes, and are not supportive of each other. The training team must also be able to anticipate and adapt to the dynamics of the larger multilevel organizational system in which it operates.[25]

Training programs at the University of Wisconsin and at the University of California San Francisco take into account multilevel organizational factors to create an environment that is conducive to transdisciplinary training.[6,26] Training in these programs is flexible and provides access to a wide range of training opportunities (e.g., courses, seminars) and laboratory research experience across many departments. For example, the program at Wisconsin, directed by Davidson,[6] has graduate students in psychology taking courses in neuroanatomy and neurophysiology in the medical school and magnetic resonance physics in the department of medical physics. The training faculty are collaborative in their approach and come from departments with very good interdepartmental relationships.

Consistent with an organizational psychology framework regarding work groups and teamwork, the discussion that follows highlights factors that also relate to transdisciplinary training effectiveness. Some of these factors, termed antecedent factors by Stokols and colleagues,[10,11,27,28] are pre-existing within individuals and institutions. Other factors, termed intervening processes, occur during the training. Figure 1 shows how facilitating factors combine with challenges in transdisciplinary training to influence training outcomes.

Individual-Level Factors

For trainees, mentors, and program directors, the possession of the following characteristics will greatly enhance training effectiveness.

Communication. Confusion and lack of clarity are inherent in the transdisciplinary training process. The ability to communicate is an essential skill for transdisciplinary trainees, mentors, and program directors. Program directors and mentors who communicate clearly with minimal technical jargon help the trainee from becoming confused and frustrated. Understandable communication also facilitates the trainee's ability to learn the language of the unfamiliar discipline. The trainee is responsible for seeking clarification at those inevitable times when there is a lack of understanding. Communicating openly and often is necessary for trainees, mentors, and directors to build all-important trust.

Trust. Trust, an essential ingredient in any close working relationship, is especially critical in the relationships among trainees, mentors, and directors in transdisciplinary training programs. Considering the professional risks assumed and the somewhat speculative nature of the programmatic research undertaken, the trainee must willingly trust in the transdisciplinary training process and in the judgment of mentors and program directors. Trust allows the trainee to expose vulnerabilities associated with not knowing, and to seek information about basic aspects of a specific disciplinary approach. With trust, the trainee is willing to leap into the disciplinary divide, wallow in its uncertainty, and be guided by mentors down a research and career path with an uncertain outcome. The trainee's trust of mentors cannot be blind; some amount of savvy is needed in knowing the role of each mentor and who and when to trust in navigating multiple mentor relationships.

Characteristics consistent with the transdisciplinary ethic. There are core characteristics involving attitudes and behaviors that reflect an ethic that allows trainees, mentors, and program directors to navigate the transdisciplinary research and training process.[2,12,13,22,27] The characteristics (Table 1) provide protection from becoming parochial about a trainee's primary discipline and from regressing back to what is familiar. They

Table 1. Characteristics consistent with the transdisciplinary ethic

Openness and respect for different disciplinary approaches
Desire to work in collaborative teams involving multiple disciplines
Broad-gauged contextual thinking
Interest in using multiple methodologic tools
Intellectual curiosity and willingness to take intellectual risks
Tolerance for uncertainty
Self-assuredness and non-defensiveness when not knowing
Assertiveness in seeking clarification
Optimism, tenaciousness, and willingness to operate without clear, immediate rewards
Ability to lead and foster mutual respect and trust in others

keep the trainee from becoming too discouraged when confronting multiple challenges and when tangible rewards are not immediately apparent. The characteristics are important for learning to participate in and lead collaborative teams.

Funding Agency and Training Institution-Level Factors

Funding. Funding agencies are essential in dedicating dollars to transdisciplinary training for building and maintaining a training infrastructure, supporting trainee stipends, funding faculty to develop and implement specialized curricula, and evaluating program effectiveness. The National Cancer Institute (NCI)'s Cancer Education and Career Development Program (NCI R25T) mechanism is an excellent example of support for developing innovative transdisciplinary training structures and curricula. Funders can be helpful by actively working with training directors to ensure that the training does not regress to the confines of individual disciplinary approaches.[2]

Training program leadership and institutional structures. The presence of an influential, strong, and committed training director is critical to the success of a transdisciplinary training program.[2,3,11,13] The most effective training directors are those who are well-respected, trusted, and convincing in communicating a shared vision to all stakeholders, including institutional administrators, research faculty, mentors, and trainees. Effective directors build and maintain the training structures as well as manage the training processes. Maintaining an awareness of the system dynamics and implementing measures for problem prevention and resolution are important in protecting the most vulnerable training resource, the trainee.

Within the institution, designing physical space, structuring academic operations, and creating incentive structures for cross-disciplinary science are essential for fostering cross-disciplinary learning and collaboration.[13,19] Factors found to enhance science integration—and the likelihood of the serendipitous develop-

ment of innovative ideas between trainees and mentors—include proximity of research space among collaborators, streamlined administrative arrangements, and a history of collaborations between participating departments that are closer in disciplinary scope.[10,11,13,15,27] It may be necessary to physically and structurally separate research and training centers from traditional departments instead of trying to overcome the impediments to transdisciplinary training that exist in traditionally structured institutions.[18] Davidson[6] notes that at Wisconsin he has the advantage of having the medical school and campus-based departments in close proximity.

Intervening Processes During Training

Separate from the antecedents that are in place prior to training, intervening processes during training can help the trainee to feel respected, valued, and supported; keep the training process on course; and counteract the natural tendencies to regress to the familiar disciplinary approach.[10,11]

Time. The availability of adequate time is necessary for the transdisciplinary training structure and process to develop.[17,27] Time allows for effective communication to occur, trusting relationships to build, different disciplinary languages to be understood and spoken, transdisciplinary values to develop, and theoretical knowledge and methodologic skills in other disciplinary approaches to be learned. One example of protecting time for transdisciplinary training is the NCI Cancer Prevention Fellowship Program's providing scientists release time from other duties so they can engage in training activities for fellows.[8] A second example is the NCI R25T funding mechanism, which provides partial salary support for investigators to create innovative transdisciplinary curricula. An initial investment in time will enhance the quality of the outcomes and eventually yield a savings of time once the transdisciplinary structure and processes are in place.

Defined research problem and an individualized training plan. Wallowing in uncertainty is inherent in the transdisciplinary learning process. Guarding against unnecessary wallowing is important so that the trainee is able to avoid prolonged aimlessness and lack of development. Two keys to ensuring progress toward training goals are (1) focusing training on addressing a specific research problem, rather than trying to indiscriminately master all theoretical and methodologic aspects of each disciplinary approach, and (2) maintaining a reasonably limited disciplinary scope in training.[13,18,22]

A clearly defined research problem helps to anchor the trainee's programmatic research development and the transdisciplinary training process. The research problem also orients the training director, mentors,

Table 2. Components of an individualized training plan

I. Trainee
II. Programmatic research objective
III. Mentoring team
    A. Primary mentor
    B. Secondary Mentor 1
    C. Secondary Mentor 2
    D. Advisor
IV. Competencies to attain
    A. Transdisciplinary training and research process
    B. Content knowledge (Discipline 1, Discipline 2, Discipline 3)
    C. Research methods (Discipline 1, Discipline 2, Discipline 3)
    D. Manuscript writing
    E. Grantsmanship/grantwriting
    F. Research ethics
V. Methods to attain competencies
    A. Didactics
        1. Courses
        2. Seminars
        3. Journal clubs/brown bags
    B. Mentored research experiences
        1. Mentor projects
            a. Primary mentor project (project aim, trainee role)
            b. Secondary Mentor 1 projects (project aim, trainee role)
            c. Secondary Mentor 2 projects (project aim, trainee role)
        2. Independent research projects (project aims, trainee roles)

and trainee in developing an individualized training plan. In defining the research problem and the disciplinary scope of training, the horizontal and vertical disciplinary integrations should be complementary and balanced.[10,27] A trainee who is being trained across disciplines that are too divergent can feel fragmented and polarized, which intensifies the pull back into the familiar disciplinary approach.[27] If a trainee's program is too narrow in disciplinary focus, potential innovation can be suppressed.[18]

An individualized training plan can be used to map the training process and content around the defined research problem.[22] Table 2 outlines the components of an individualized training plan.

Mentoring structure and processes. In transdisciplinary training, students can benefit enormously from the team-mentoring structure, with each mentor representing a different discipline.[6] Team mentoring provides a breadth of experience that is unattainable through any single mentor. In team mentoring, each mentor helps the trainee to learn the content and skills of a particular disciplinary approach. In addition, each mentor also has a responsibility to help the trainee shift in and out of each discipline and work in the space between the disciplines. A mentor within the trainee's primary discipline has the responsibility of helping the trainee to move the beyond the discipline. A mentor in

a complementary discipline has the responsibility of ensuring that the trainee is receiving relevant and sufficient coverage of that discipline's approach.

Frequent meetings, both scheduled and impromptu, are important. Regular meetings among members of the mentoring team and training directors keep the training process coordinated so that everyone works toward the stated objectives in the training plan. In situations where individuals involved in training lack proximity, reliance on telecommunications and other forms of electronic technologies helps to maintain as much contact as possible. Kaplan at Wake Forest University and Manuck at the University of Pittsburgh[5] do not let being at different institutions impede their communication. They take advantage of technologic advances in communication to stay in regular contact and to seamlessly exchange data and manuscripts. They note that they probably spend as much time in contact with each other as either does with his colleagues at the same institution. There is no substitute, however, for face-to-face contact.[29]

Meta training about the transdisciplinary research and training process. The training process can be explicit in helping the trainee understand how to manage the unique aspects and challenges of engaging in transdisciplinary training. Training can include helping the trainee to (1) understand the conceptual distinction of transdisciplinary training; (2) learn how to manage the obstacles and capitalize on the facilitators existing at the institutional, program, and individual levels in transdisciplinary training and research; (3) manage the unique career-development challenges related to securing academic jobs, funding, publication, promotion, and tenure; and (4) develop strategies to facilitate shifting in and out of disciplinary frameworks and working between frameworks that are paradigmatically different. The program can help the trainee to know the cultural and instructional styles of the different disciplines and how well they intersect with the trainee's own learning style. The knowledge and skills related to transdisciplinary training and research can best be developed through a combination of formal didactics, research experiences, and mentorship.

Future Directions

There is much written but little known empirically about training across disciplines. There is an opportunity to (1) develop a better understanding of the operational distinctions of different integrative training approaches, (2) empirically determine the effective elements of transdisciplinary training models, (3) define the outcome metrics appropriate at different time frames, and (4) create toolkits to help with training process and administration.[10,11]

Table 3. Indications of transdisciplinary qualities in scholarly products

Transdisciplinary scope of the research topic and its conceptualization
Diversity of research methods used in the study
Contextual scope of the author's conceptualization of the research topic
Hypotheses generated that synthesize theoreticaltheoreticalalal frameworks from different disciplines
Levels of analysis bridged
Co-authors from different disciplines

Note: Adapted in part from Mitrany and Stokols[15]

Making Operational Distinctions Among Conceptually Different Forms of Integrative Training

Multidisciplinary, interdisciplinary, and transdisciplinary training have different training objectives. There is yet no clear articulation of how the various training approaches differ in structures, methods, or processes to achieve the different objectives. Nor is it known what specific elements of training are critical to the transdisciplinary trainee's being able to synthesize theoretical and methodologic aspects of different disciplines.

Empirically Identifying the Effective Elements of Transdisciplinary Training Models

There have been few empirical efforts that examine the transdisciplinary training process and outcome.[11,15,22,30] The development of theoretically based qualitative and quantitative methodologic approaches is needed to identify (1) essential individual characteristics in trainees, mentors, and program leaders; and (2) key institutional qualities, training structures, and processes that relate to training success.

Defining the Metrics and Time Frames of Outcome

The ultimate determination of success will be the eventual impact that trainees have as scientists who use integrative theoretical perspectives and methodologic approaches to improve the nation's health. At present, the more immediate focus can be on evaluations of the quality, novelty, and scope of the disciplinary integration in the trainees' work at different time points during and following training.[10,11,15,21] Figure 1 displays some of the outcomes that can be considered at different time points. Outcome assessments can build on the initial work of Stokols and Rosenfield.[11,15] Table 3 lists criteria that can be considered indicators of disciplinary integration. Also needed is the establishment of other indicators of program effectiveness beyond trainee performance, such as the performances of the mentors and the effectiveness of the program.

Developing Training Toolkits

A greater empirical understanding of transdisciplinary training processes and outcomes can help inform the development of training toolkits.[11] Training toolkits can contain materials to be used by training directors for multiple purposes, including training and evaluation. Examples of toolkits used for training purposes include (1) helping the trainee to understand the uniqueness, challenges, and the processes of transdisciplinary training and research; (2) helping the trainee to develop some of the essential transdisciplinary values and skills competencies; and (3) guiding mentors in training transdisciplinary scientists, especially mentors who work with trainees outside their primary discipline. Examples of toolkits used for evaluation purposes include (1) audits of training readiness to assess the presence of transdisciplinary characteristics in prospective trainees,[11] (2) audits of mentoring readiness for potential mentors, and (3) assessment methods and measures to monitor ongoing processes in transdisciplinary training and to evaluate outcomes. Toolkits used for evaluation purposes will benefit from the development of common definitions and standards of what constitutes adequate evidence.

This is an exciting time in the evolution of science and the training of scientists. Disciplinary integration is increasingly called upon to address the complexities of health problems. The integration of disciplinary research creates new hybrid disciplines (e.g., genetic epidemiology) and, in a reciprocal way, influences the way disciplinary science is conducted. Today's transdisciplinary training has great potential to affect tomorrow's mentoring models in innovative ways. Now is the time for the scientific community to take action to better delineate the different integrative training approaches, identify their effective elements, and determine their long-term impact.

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